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INLAND WATER SURVEY COMMITTEE

Third Annual Report
1937-38

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INLAND WATER SURVEY COMMITTEE

Third Annual Report, 1937-38

To The Right Honourable WALTER E. ELLIOT, M.C., M.P.,
Minister of Health
and
The Right Honourable JOHN COLVILLE, M.P.,
Secretary of State for Scotland.

GENTLEMEN,

We have the honour to submit the following Report on our work for the year 1st April, 1937, to 31st March, 1938:—

1. During the year under review Dr. E. B. Bailey, M.C., F.R.S., Director of the Geological Survey of Great Britain, has been appointed an Assessor to the Committee in the place of the late Dr. Bernard Smith, F.R.S. We welcome Dr. Bailey in the knowledge that his ability and keenness will greatly benefit the work of the Survey.

2. Our terms of reference laid on us the task of collecting, correlating and encouraging the keeping of records of the water resources of Great Britain and of making these results available for general use. As was explained in our two previous Reports* the actual work of gauging and recording is not carried on by us directly but by various local bodies and organisations, the task of the technical officers attached to or assisting in the Survey being to examine and co-ordinate the information supplied by the local agencies and bring it into a form suitable for publication. We are assisted as regards surface water records by the Ministry of Agriculture and Fisheries, the Ministry of Health, the Department of Agriculture for Scotland, the Department of Health for Scotland and the Fishery Board for Scotland; as regards underground water by the Geological Survey; and in matters relating to rainfall by the Meteorological Office.

Progress of Survey.

3. The greater part of the past three years' work has been taken up in the considerable amount of preliminary exploratory work which was found to be necessary and in completing the preparation and arrangement of the first of an annual series of volumes of statistical records relating to the Surface Water Resources of Great Britain.

4. In a Memorandum presented by them in March 1938 to the Royal Commission on the Geographical Distribution of the

* Published by His Majesty's Stationery Office 1936 and 1937, price 3d. and 6d. respectively.

Industrial Population the Federation of British Industries stated that information in regard to water resources in various regions was very necessary if industries were to be re-located. The same need must equally be felt whenever certain types of industrial undertakings are trying to establish themselves for the first time.

5. We have noted the recommendation in the Fourth Report of the Joint Advisory Committee on River Pollution that there should be established in each river-basin a single comprehensive authority " in whom should be centralised the functions relating to river pollution prevention, land drainage, fisheries, water abstraction and, in suitable cases, navigation ". If such bodies were established, water-survey would naturally fall amongst their functions as heirs to the Catchment Boards, inasmuch as the results of such a survey would be a necessary preliminary to any satisfactory evaluation of the hydrological conditions which affect each and all of these interests.

Surface Water.

6. Having completed three years' work we consider the time to be opportune to take stock of the progress so far made in the Survey, and that likely to be achieved in the future. We are convinced that a survey of water resources of real use needs to be comprehensive as that carried out by the Ordnance Survey or the Geological Survey in their special fields. We have found, however, that relatively very few reliable records of river flow are now being kept. We have no staff at our disposal for taking actual measurements and we have to rely in England and Wales (and to some extent in Scotland) on voluntary action by Catchment Boards and others for execution of this part of the work of the Survey. Our experience has shown that neither the information available from water undertakers nor that from Catchment Boards is sufficient in scope or adequate in quality to enable a comprehensive survey to be made. We have reluctantly come to the conclusion that in spite of the useful work which has been done by the technical officers attached to or assisting in the Survey in bringing to the notice of Catchment Boards and others the desirability of utilising standard methods of gauging, there is little prospect of any satisfactory progress being made unless additional effective arrangements can be introduced for securing the systematic and continuous gauging of rivers throughout the country. We have, therefore, felt it our duty to advise the Government of the position and to urge that action should be taken which will create the necessary agency and finance to perform this essential work; moreover, in order that the work already initiated in

Scotland should be maintained and extended, the facilities which, through the Department of Agriculture for Scotland, have already been provided should continue to be made available.

7. Meanwhile, the Survey has proceeded on the lines explained in our first and second Annual Reports and we have continued to encourage the measurement of surface water resources by Catchment Boards and other bodies interested in the resources of rivers, though in England and Wales this progress has not always been as rapid as was at first hoped.

8. Such Catchment Boards as are active, as well as the Department of Agriculture for Scotland, have in the course of their work experimented in several directions, in efforts to discover the forms of technique most suitable for this country. Various kinds of current-meters, cableways for moving meters across river-sections, weights to sink the meters vertically, velocity-measuring floats, level-recorders of both the float and pneumatic types, and decimal scales for staff-gauges, have been used and compared.

9. The Department of Agriculture for Scotland were again authorised to spend £500, upon water-survey work during the year under review. The existing level indicating and recording stations upon the Clyde, Kelvin, Irvine and Tay were maintained and stations were established upon the rivers Earn (Perthshire), Eden (Fife), Tyne (East Lothian) and Nith; the River Tweed basin has been reconnoitred. The Department is now occupied, so far as its other duties allow, in calibrating the rivers at these stations. This work is being done by means of current-meters but a shortage of funds has prevented the Department from using heavy sinkers for these meters and cableways to move the meters from point to point across the river (all of which equipment is normal for rivers with such high velocities as are encountered at times in Scotland), with the result that considerable difficulty occurs in measuring the high-stage discharges at any of the stations established, and therefore in completing the calibrations. The lack of such equipment has moreover helped to narrow the choice of sites for stations and the Department has hitherto been obliged to confine itself almost entirely to using river-bridges for the purpose, despite the drawbacks sometimes associated with them.

10. Some of the Catchment Boards have found that weed-growth of changeable amount has sometimes affected gauging conditions very seriously. Others have encountered difficulties in finding suitable sites and in laying-out the stations and obtaining the consent of riparian owners to the erection and maintenance of gauging instruments with consequent delay

in the establishment of the stations. We consider, however, that the extension of survey work which has taken place is as satisfactory as can be expected and that there is a great keenness amongst most of the engineers concerned for the extension of this work so far as their resources allow.

11. The survey of a river should extend not only over its lower reaches but also to the tributaries and upper reaches. This is particularly the case in areas suitable for potential development for water or power supply, since a comprehensive survey of the river system is needed to provide a background for any scheme brought forward by any undertaking for the use of surface resources. Without this background it is hardly possible for interests, who may think themselves affected by the scheme, to bring it into correct perspective in relation to the remaining resources of the river system and the needs of other users. Our experience over three years has emphasised that a comprehensive survey of an area would lead to co-operation between those interested in or needing to utilise the water resources of the region; it would facilitate sound and rapid discussion of any particular scheme in that area and would probably lead to the adjustment of at least some of the difficulties that arise.

12. We have found that it is often thought that there is necessarily a clash of interest between water undertakings and Catchment Boards. The interests of these bodies should be in fact complementary and we would urge that where possible water undertaking engineers and Catchment Board engineers should co-operate in the exchange of information. In one case where it has been arranged that the results of river gaugings made by a water undertaker are submitted to us through the agency of a Catchment Board an exchange of information which resulted has already been found to be very valuable.

13. It has been represented to us from time to time, especially by laymen, that where financial resources are limited, programmes of constructional works must take precedence over expenditure on gauging. We appreciate that constructional works are often essential to meet the immediate needs of the authority and that, while they provide immediate and visible evidence of how money has been spent, expenditure which is not obviously productive has to be incurred over a number of years before the full benefits of river measurement can be realised. We would, however, emphasise what is generally recognised amongst those engaged on the technical side of the work, that constructional works are often undertaken without a full knowledge of all the conditions they are designed to relieve and that without this knowledge of the river's behaviour

throughout an extended period of time the works can at best be experimental only. Survey work that has been maintained for substantial periods both before and after any work has been done will moreover help to determine beyond dispute the effects of such work, and so enable anyone concerned to deal correctly with any claims for damage that may arise. It is in our opinion a short-sighted policy to concentrate, often at great expense, on immediate and visible results which are open to the risk of proving later on to be insufficient to meet practical requirements.

Underground Water.

14. For many years the Geological Survey memoirs on Water Supply have been published on a "county area" basis. The plan has now been changed to one of a rectangular grid. For this purpose the sheets (or half or quarter sheets if more convenient) of the Quarter Inch to a Mile Geological Survey Map have been chosen as being more convenient for general purposes for present day use. Practical difficulties were foreseen in the adoption of the river-basin as the unit.

15. A memoir dealing with the eastern half of the area of the Quarter Inch Geological Map, Sheet 15, which includes Northampton and Oxford, is now in preparation. For this memoir a series of isopachyte maps is being constructed, which show the outcrops and concealed extensions, local changes in thickness, and contours of the upper surface relative to Ordnance Datum of each water-bearing formation. From these maps estimates of the depth from surface, and of the thickness of these formations may be made for any specific locality within the area of the sheet. Isopachyte maps for the Marlstone and the Northampton Sand have been completed. The field work referred to in the Second Annual Report as being carried out in the Nene Basin, has been extended to cover the remainder of this half-sheet.

It is proposed that short-term intensive studies of the fluctuations of water tables in the various formations should be carried out from time to time in individual river basins.

16. The Geological Survey are endeavouring to collect information from water engineers and others on water levels in selected wells in various parts of the country, particularly from Chalk districts. It is known that numerous companies and private individuals interested in water supply make frequent observations of certain wells and an effort is being made to obtain permission to utilise the records. It is hoped also that much information on bournes or intermittent streams

of the Chalk will be gathered by the scientific societies and field clubs located on or near the Chalk outcrops of the country, particularly in South-Eastern England. This will include information on former bourne-flows, the recording on maps of sites of temporary springs, and paths of bournes, and observations of such outbreaks of water in the future. Correlation of information so obtained will be valuable in estimating seasonal fluctuations in the water table in different localities on the Chalk outcrop.

Rainfall.

17. Progress has been made during the year in securing additional rainfall records from areas for which little information has previously been available, in many cases with the co-operation of the Engineers of Catchment Boards. Some progress has been made in the valuation of the general monthly rainfall and of the average monthly rainfall over areas for which there are run-off records.

18. A series of monthly percentage maps on a comparable basis has been completed, covering the period 1870 to date. The maps are for the British Isles and on a scale of 60 miles to one inch. They are available for reference and are likely to be of service in any investigation as to the fluctuations of monthly rainfall experienced since 1870 in any part of the country.

Preliminary Examination of Individual River Basins.

19. Below we give, in continuation of those in the First and Second Annual Reports, the results of the preliminary examination of seven river basins.

River Earn (*Perthshire*).

20. The River Earn flows out of Loch Earn and after traversing pastoral and agricultural land discharges to the tidal portion of the Tay some distance below Perth. The altitude of Loch Earn is 317 feet and its area about 3·7 square miles. The principal tributaries are, on the right bank, the Water of Ruchill which flows down Glen Artney, the Ruthven Water which rises in Gleneagles, and the Water of May which rises on the north slopes of the Ochil Hills. On the left bank the main tributaries are the River Lednock flowing down Glen Lednock and the Turret Burn which flows out of Loch Turret and discharges its waters into the Earn at Crieff. The total area of the Earn basin, including Loch Earn, is approximately 380 square miles. The river is under tidal influence for a distance of 8¼ miles above its junction with the Tay.

21. The average annual rainfall varies from about 30 inches at the junction of the Earn with the Tay to about 80 inches on Ben Vorlich and 90 inches in the extreme western part on Mealtant-Seallaidh and Creag-MacRanaich. The mountains rising around Loch Earn receive an average annual rainfall of over 70 inches. The area is well represented in the lower levels by rainfall stations but there are very few in that part where the average exceeds 60 inches.

22. With the assistance of the Department of Agriculture for Scotland, an automatic water level recorder has been installed at Chapelbank. The area drainage to this point is 284 square miles. Staff gauges have also been erected at Chapelbank, Kinkell Bridge, Ross Bridge, Comrie and St. Fillans.

23. An important dislocation known as the Highland Boundary Fault brings into juxtaposition two regions of highly contrasted geological character, the Central Highlands and the Midland Valley of Scotland. The Earn basin lies partly within the one and partly within the other. The strata in the mountainous region belong to the Dalradian Series, highly metamorphosed sediments comprising compact grits, mica schists, slates and subordinate limestones, with intruded igneous rocks. All these rock types are too compact to retain much water except in fissures and fractures. The area is largely free of glacial deposits. East of the Highland Boundary Fault the river traverses strata of Lower Old Red Sandstone age, comprising a lower group of volcanic rocks and an upper group of sandstone. The volcanic group is not much in evidence at the Highland Boundary Fault, but at Forgandenny its outcrop is nearly a mile in width. Moderately thick deposits of boulder clay, glacial sands and gravel, and, below 100 ft. O.D. marine alluvium, are widespread. The sandstones may prove water-bearing but as the area is almost wholly agricultural no deep wells are known.

River Eden (*Fife*).

24. The Eden rises at a height of between 800 and 1,000 feet on the southern slopes of the Ochil Hills, with small tributaries rising on the north slopes of the Lomond Hills, and flows through Fife in an easterly direction to St. Andrews Bay about three miles north of St. Andrews. It drains an area of approximately 124 square miles and passes through agricultural country during the whole of its course. For about two miles above Guardbridge the river is under tidal influence. The principal tributary on the right bank of the river is the Ceres Burn, which drains an area of approximately 26¼ square miles.

25. The average annual rainfall varies from about 25 inches on the east coast near Kingsbarns and Fifeness to 40 inches in the neighbourhood of Glenfarg. The rainfall over the Lomond Hills exceeds 35 inches. There are few rainfall stations in this area and more stations are desirable, especially in the western part.

26. The Department of Agriculture for Scotland has established a recording gauge at Victoria Bridge, Cupar, and staff gauges at Kemback on the Ceres Burn, and at Ramornie Bridge, Pitlessie.

27. The River Eden traverses practically only one formation, Upper Old Red Sandstone, but volcanic rocks occur in the hills to the north and to the south. The Upper Old Red Sandstone comprises red and yellow sandstones. Superficial deposits of boulder clay and glacial gravels cover most of the area. Borings for water are not numerous, but some yield a moderate supply.

River Tyne (East Lothian).

28. The Tyne rises at a height of about 700 feet on the northern slopes of the Lammermuir Hills and flows through East Lothian to the sea a few miles west of Dunbar, draining an area of approximately 122 square miles, chiefly pastoral and agricultural land. Near Pencaitland, Haddington and East Linton the natural flow of the river is interrupted by weirs which divert the waters for power for small industrial concerns. For about four miles upstream from the coast the river is subject to tidal influence. On the right bank Coalstown Water which rises at an altitude of 1,500 feet and drains an area of approximately 29 square miles and the Birns Water which rises at an altitude of about 1,000 feet and drains an area of approximately 37½ square miles, flow into the river.

29. The average annual rainfall over the Tyne basin varies from about 24 inches along the coast north of Dunbar and to the north of East Linton to 40 inches in the vicinity of the Hope Hills, part of the Lammermuir Hills. There are few rain-gauges in use in this area and these are mainly situated in the Lammermuir Hills. More rainfall stations are desirable, especially at Haddington and East Linton.

30. With the assistance of the Department of Agriculture for Scotland an automatic water level recording gauge has been installed at Phantassie Bridge near East Linton, and staff gauges have been erected at Phantassie and Samuelston.

31. The River Tyne traverses in succession strata of

Ordovician and Lower Carboniferous age. Within its basin are also outcrops of Upper Old Red Sandstone. The Ordovician rocks are compact grits and graywackes with very subordinate shale bands. The Upper Old Red Sandstone is composed of sandstones and occasional beds of red marl. The formation is water-bearing and yields moderate local supplies. Almost from its source as far as Haddington, the river traverses medium to fine-grained sandstones with partings of shale and limestones of Lower Carboniferous age. Between Haddington and the sea the basin is occupied by volcanic rocks. Some of the thicker beds of sandstone in the Carboniferous formation yield water. The volcanic rocks do not yield much except along crushes and fissures. Except upon the hills and areas of volcanic rock a thick deposit of stiff boulder clay covers the strata. Overlying the boulder clay are occasional areas of glacial sands and gravels from which springs issue, which in some cases have been utilised.

River Trent.

32. The River Trent has a total drainage area of 4,029 square miles. The limit of tidal influence is about five miles below Newark. Roughly midway along its course is Nottingham, to the south and west of which, either wholly or partly within the basin, are important industrial areas of the Midlands and the Potteries.

33. The average annual rainfall over the Trent basin shows little variation over the greater part of its area, being about 25 inches, but it exceeds 40 inches in the north western part of Staffordshire. There are many rainfall stations in this area and these are fairly evenly distributed.

34. The minimum water-levels of the Trent itself are controlled for navigational purposes by weirs, from the junction of the Derwent to the beginning of the tidal reach. This control hampers the measurement of the low-stage discharges of the river, which are the most frequent. The River Trent Catchment Board have a gauging-station at Nottingham but do not at present claim accuracy for their low-stage discharge-statistics. They also use for measuring purposes a weir 500 feet long on the Soar at Leicester and another 300 feet long on the Derwent at Derby but at these two points also there is a lack of accuracy in measurement, due in both cases to the length of the weir.

35. No other discharge measurements have been reported for the Trent and its main tributaries, except at two places. The Derwent Valley Water Board gauges the River Derwent in its

upper reaches at Yorkshire Bridge near Bamford where the drainage area amounts to 48·9 square miles by means of a throated flume of a noteworthy pattern capable of measuring up to 9,000 cusecs (4,840 m.g.d.). The South Staffordshire Waterworks Company has since September 1937 been measuring with a throated flume the discharges of the River Blythe at Hamstall Ridware, the drainage area being 62·5 square miles. Measurements of run-off are made by less than half-a-dozen undertakings on minor tributaries, the only area of substantial extent being one of 10·9 square miles on the Bourne Brook, near Lichfield, gauged by the South Staffordshire Waterworks Company.

36. It is a matter for regret that surface-water survey should be so backward in this important river-basin, in which water abstraction for industrial and domestic purposes, navigation, fisheries, land-drainage and water-pollution are all matters of considerable importance and liable to affect one another. We hope accordingly that it will soon become possible for such survey to be undertaken much more thoroughly and comprehensively by the Catchment Board who are very active in other directions.

37. The greater part of the rocks which crop out in the Trent basin are of Triassic age, and occupy the low-lying ground between Nottingham and the Humber and of the Midlands. They consist of sandstones and pebble beds of the Bunter and sandstones and marls of the Keuper formations. These sandstones and pebble beds, especially the Bunter, yield very large supplies of underground water for the industrial towns in Nottinghamshire, Staffordshire and Warwickshire. The Magnesian Limestone, underlying the Bunter, is also water-bearing, and outcrops in a belt, some 5 miles wide, from near Nottingham northwards to Doncaster. In the north-west of the basin, the Carboniferous Limestone Series and Millstone Grit outcrop in the hilly catchment area of the Derwent, and yield important overground supplies collected in impounded reservoirs for the Derwent Valley Water Board. Underground supplies are also obtained from the Millstone Grit between Derby and Nottingham. The Potteries Coalfield in the north-west, and the South Staffordshire, East Warwickshire, Leicestershire and Nottinghamshire Coalfields in the southern part of the Basin, with their numerous industrial towns, get the bulk of their water supplies from underground sources in the adjacent overlying Triassic rocks which flank them.

Drift deposits overlie the solid rocks in many districts, sands and gravels being well developed in the river valleys, and at Burton-on-Trent yield most of the water used for brewing.

River Great Ouse.

38. The Great Ouse is the principal river of a group draining into the Wash, whose water measurement presents considerable difficulty. It drains an area of 3,200 square miles.

39. The average annual rainfall over the basin of the Great Ouse is for the most part about 25 inches. The average rainfall is less than this in Cambridgeshire and parts of the neighbouring counties while it exceeds 25 inches in Oxfordshire and Hertfordshire. The area has a number of rainfall stations, which are well distributed, but owing to the prevalence of intense local rains a closer network of stations is desirable.

40. Ansted*, who writes of the Great Ouse as having " the most tortuous course of any river in the British islands," remarks of the group mentioned above that

> " through the greater part of their way through the clays of the oolitic group of rocks (they) are very sluggish. They are subject to floods whenever heavy rains fall on the uplands and can only expand over the flat plains through which their courses lie. To enable them to reach the sea it is sometimes necessary to construct extensive works preventing the influx of the tide, and enabling the water to be drained off during low water. To permit even this their meandering course has to be straightened, so as to render their small fall available. Sometimes they require to be lifted and conveyed to the sea by artificial channels ".

In such circumstances the water-levels of the Great Ouse itself and its auxiliary, the Hundred Foot River, being governed by artificial means provide no index to the flows of the river-system, and the substitution of the comparatively simple measurement of water levels for the sometimes troublesome or costly direct measurement of discharges in the daily or more frequent observations that are necessary is practically impossible. Weeds and navigation works also affect these levels, so that at different seasons at one and the same point any given water-level will represent different volumes of flow. These difficulties affect also tributaries of the Great Ouse like the Cam, Lark and Little Ouse (or Brandon).

41. The River Great Ouse Catchment Board are at present the only authority undertaking any volumetric surface-water survey of importance in this river-basin. To reduce the volume of work involved, which might otherwise become burdensome for reasons already given, they make discharge measurements mainly by means of floats rather than mechanical current-

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* "Water and water supply, chiefly in reference to the British Islands—Surface water", by Professor D. T. Ansted, London, 1878.

meters. Even so, the float measurements have to be made at least once daily, whereas if water levels had been a sufficient index of discharges a weekly visit to the recording instrument would have been all that was required. For results to be computed accurately from observations with floats it is necessary to select certain coefficients for each station individually and the task of selection is in the present state of knowledge not always an easy one. The staff of the Catchment Board are, despite the demands of other work, trying to improve the accuracy of the measurements made, but, until water-survey of a general nature is accepted by the Board as one of their functions, the gauging operations are not likely to be either as accurately performed or regularly conducted as is desirable, whilst much of the material collected will have to remain in an undigested form.

42. Outcrops of various clay formations of Jurassic age occupy the greater part of the Great Ouse basin, particularly the widespread area of the sequence of Oxford Clay, Ampthill Clay and Kimmeridge Clay This belt of clay land runs approximately from south-south-west to north-north-east, and the main stream more or less follows this direction. Absorption into water-bearing beds is practically absent over this tract. To the north-west, the Upper Lias, the Northampton Sands, and oolitic limestone of the Inferior Oolite and Great Oolite Series, including the Cornbrash, crop out; these are often water-bearing in relatively small degree; numerous springs are thrown out at the junctions of pervious and impervious beds. To the east and south-east occur Lower Greensand, Gault, Upper Greensand and Chalk, all except the Gault being aquifers. Large areas of both oolitic rocks and Chalk are blanketed by impervious Boulder Clay.

River Wye.

43. The Wye drains an area of 1,597 square miles, a large proportion of which is mountainous. The Wye and its tributaries drain areas including parts of the ranges of Plynlimmon, Drygarn, Radnor Forest, Mynydd Eppynt and the Black Mountains, parts of which are at a height of well above 2,000 feet.

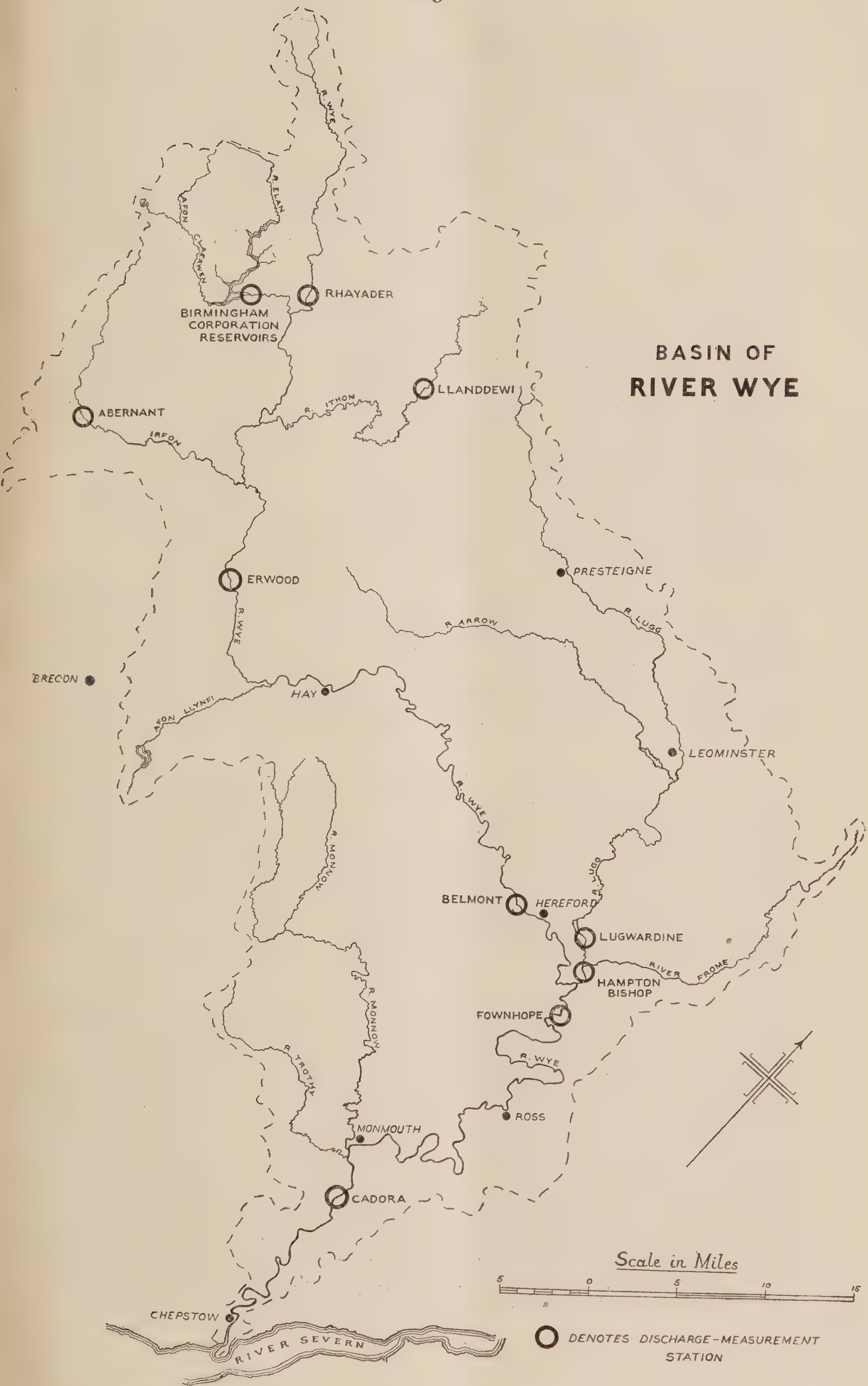
44. The average annual rainfall over the Wye basin varies from about 30 inches at its mouth to over 80 inches in the neighbourhood of Esgair Garthen in Radnorshire and in the area in Montgomeryshire just south of Plynlimmon. The Birmingham waterworks areas where the rainfall is high are well represented by rainfall stations, but additional stations in other parts of the basin are desirable.

45. The River Wye Catchment Board is at present engaged in executing a grant-aided flood-alleviation scheme. The scheme has necessitated a surface-water survey and the Board is active at nine discharge-measurement stations as shown in the accompanying map. Partly owing to the rocky nature of much of the river-beds, suitable sites for gauging work are not numerous. Work in some reaches of the Wye itself is, as in the Great Ouse, hampered also by the seasonal growth of weeds. It appears that in such cases the stage-discharge relationship varies from time to time during the period of weed-growth, which may last from May or even earlier until November, when the increasing river-flows tend to remove the weeds. Any such unstable state of affairs usually requires frequent direct measurement of discharges as well as of water-levels. It will soon be all the more difficult to meet this need since most of the water-survey work will probably cease as soon as the improvement scheme has been completely executed.

46. Apart from the work of the Catchment Board there is no volumetric survey being conducted in the basin, except that of the Birmingham Corporation. This authority has since 1908 measured the rainfall and run-off of its gathering grounds 71·2 square miles in extent, one of the gauging-instruments used being the overflow cill, 600 feet in length, of the Caban Coch Reservoir, there being, however, a level-recorder at either end of the cill.

47. The Wye undoubtedly possesses valuable water-resources, which should be surveyed properly if they are to be utilised without detriment to any of the several interests involved. We appreciate, however, that the Catchment Board are not well situated financially for undertaking such work at their own expense in comparison with Boards such as that of the Trent where the rateable value for land drainage purposes per square mile is more than twelve times as great as that of the Wye basin.

48. The surface rocks of about two-thirds of the Wye basin consist of red marls, and red, green and brown sandstones with beds of Cornstones, of Old Red Sandstone age. Over almost the whole of the remaining third, lying in the north-western part of the basin, Silurian shales, mudstones and grits with occasional conglomerates and limestones, crop out. Some igneous rocks also occur in this area. Small tracts of Carboniferous Limestone, Coal Measures, and Triassic rocks lie in the South and south-eastern part. The chief water-bearing formation is the Old Red Sandstone, from the upper part of which some fairly large yields are obtained from underground sources.


BASIN OF
RIVER WYE
R. WYE
R. ELAN
AFON CLAERWEN
RHAYADER
BIRMINGHAM CORPORATION RESERVOIRS
LLANDDEWI
R. ITHON
ABERNANT
IRFON
ERWOOD
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PRESTEIGNE
R. LUGG
R. ARROW
BRECON
HAY
AFON LLYNFI
LEOMINSTER
R. WYE
R. MONNOW
BELMONT
HEREFORD
R. LUGG
LUGWARDINE
HAMPTON BISHOP
RIVER FROME
FOWNHOPE
R. WYE
R. MONNOW
R. TROTHY
ROSS
MONMOUTH
CADORA
CHEPSTOW
RIVER SEVERN
Scale in Miles
5
0
5
10
15
DENOTES DISCHARGE-MEASUREMENT STATION

River Nith (Dumfries-shire).

49. The Nith rises in the Ayrshire Hills to the north-east of Dalmellington and flows mainly south-east to the Solway Firth about fourteen miles below Dumfries. The river rises at an altitude of 1,250 feet while the hills surrounding are as high as 1,500 feet. The total area of the Nith Basin is approximately 422 square miles. The principal tributaries on the right bank are the Afton Water (16 square miles), Kello Water ($11\frac{1}{4}$ square miles), Euchan Water ($16\frac{1}{4}$ square miles), Scar Water ($55\frac{1}{2}$ square miles), Cluden Water (92 square miles). The tributaries on the left bank are much shorter than those on the right bank, the largest being the Crawick Water ($35\frac{3}{4}$ square miles), Mennock Water (15 square miles), Carron Water ($14\frac{1}{4}$ square miles), and the Cample Water ($16\frac{1}{2}$ square miles). Practically all the tributaries drain from hills varying in altitude between 1,500 and 2,000 feet. The upper stretches of the Nith and its tributaries drain hill country and moorland, the middle reaches are chiefly pastoral while Nithsdale below Sanquhar is partly pastoral and partly agricultural. At Cumnoch, Kirkconnel and Sanquhar, there is coal mining.

50. The average annual rainfall over the Nith Basin varies from about 40 inches around Lochar Moss and in the vicinity of Dumfries to 80 inches on the hills south of New Cumnock and 70 inches on the Lowther Hills. A number of rainfall stations are maintained around Afton Reservoir but additional stations are desirable near Kirkconnel, Sanquhar and near Dumfries.

51. The Department of Agriculture for Scotland has established an automatic water level recorder at Auldgirth Bridge. The area draining to this point is aproximately 300 square miles. Staff gauges are established at Thornhill, at Kirkconnel and on the Cluden Water and the Scar Water. At Drumlanrig Bridge a gauge is painted on the bridge and the records have been taken here by the Estate. The Buccleuch Estates are willing to make these records available for the Committee.

52. The headquarters of the Nith lie partly on the north-west of the Southern Upland Fault, and the rocks include sediments and lavas of Lower Old Red Sandstone age, and the Lower and Upper Carboniferous strata in the coal-mining district of New Cumnock. The greater part of the drainage area lies within the Southern Uplands, and is occupied by grits, greywackes and shales of Ordovician and Silurian age. Resting on these rocks are three extensive outliers of Carboniferous and Permian strata, in the neighbourhoods of Sanquhar, of Thornhill, and at Dumfries respectively. West of the Nith estuary the drainage basin includes about half of the Dalbeattic granite mass, while in the north there is the smaller

granitic mass of the Spango Water. Superficial deposits of boulder clay are present in many districts. Along the valley of the Nith there is much alluvium flanked by fluvio-glacial sands and gravels. Water supply in the sparsely populated mountainous Ordovician and Silurian moorlands is mainly derived from springs. Water-bearing sandstones are present in the Sanquhar, Thornhill and Dumfries outliers. Large quantities of water are pumped from the Permian sandstones and breccias at Dumfries.

Publication of Results.

53. The work of examining, checking and correlating the information on charts and measurements taken by various authorities has been continued during the year and much valuable experience has been gained from this work and from visits to the sites of measurement stations. It has been possible in many cases to pass on this experience to those engaged in measurement work elsewhere. We consider that authorities who take steps as soon as possible after their records have been collected to make them productive of results on lines such as are followed in the Surface Water Year Book mentioned below, cannot but find that the work will be of much service to them. It forms a safeguard against the risk that the records may be allowed to lie idle for many years in the belief that they are potentially fertile, whereas long afterwards, when deficiencies and errors are beyond correction, it may be found that the mass of observations collected is in fact of very little value.

54. The results of measurements for twenty-eight gauging stations in fourteen river basins were in the printer's hands at the end of the year under review and have since been issued as the Surface Water Year-Book of Great Britain, 1935-6,* the first volume of what is hoped will become a standard annual work of reference. The information presented in the Year-Book should prove of greater importance as further volumes are issued since the variations from year to year in the rivers measured can be so great that several years' statistics must be collected and discussed before a reliable picture can be had of the variations in the resources of any particular area.

55. Many of the items in this first Year-Book relate to areas of several hundred square miles each, for which statistics of daily river-discharge could suitably be quoted. In the second issue (1936-7) statistics will be given also in respect of a number of gathering-grounds of a few thousand acres each. In these cases, if the stream is impounded, the amount discharged daily by the river below the reservoir may ordinarily be unimportant in amount, and the statistics published relate

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* Published by His Majesty's Stationery Office. Price 5s. od.

to monthly quantities only. In this volume contributions will also be made for the first time by a hydro-electric power company.

56. It has been found in examining and analysing records that at times the form and wording of the recorder-charts make them difficult to read or uncertain or confusing to interpret. The charts may, for example, be printed for use from 9 a.m. on one Monday to 9 a.m. on the following Monday. In practice the time of changing the chart may not be exactly at the hour or on the day given. Moreover, the heading often includes an entry-space entitled " Chart for week ending . . . ." which different persons complete in different ways.

57. We therefore recommend that an eight-day chart should be the standard arrangement for weekly records, at any rate in new installations. Some initial expense in altering the design of the recording-instruments and recorder-charts would be needed but we feel that the change would be advantageous. The proposed arrangement has been adopted already in other countries, e.g., Germany, Switzerland and the United States of America. We also recommend that the eight day-spaces might be headed "First day", "Second day", ... "Eighth day ", instead of " Monday ", " Tuesday ", etc., and that the entry-space described above should be replaced by two others, as follows:—

(a) Chart put on................day(date)..............., 193 .

(b) Chart taken off............day(date)..............., 193 .

Accuracy of Measurement.

58. During the local investigations that have been carried out by the Survey's technical staff it has been possible on several occasions to light upon unsuspected inaccuracies or inadequacies of measurement and to help in correcting them. It cannot, of course, be over-emphasised that measuring authorities should be always watching for the occurrence of such inaccuracies so that they can be remedied as soon as possible. In this way laborious correction and recompilation of figures over a long period when the error is discovered can be avoided.

59. From the examinations of existing gauging-stations that have been made, we have come to the conclusion that a large proportion of inaccuracies arise from the reluctance of water-surveyors or their authorities to endow their stations with sufficient flexibility in their measuring arrangements. The station is often related to some river-control work intended to aid navigation, milling or water-abstraction. The purpose of these structures is to maintain the river-level at a fixed stage (or retain in a reservoir as much as is allowed), however low

the river-discharge may fall, and yet, when the river approaches flood conditions (or the reservoir is full), allow the excess water to pass with the minimum of heading-up above the fixed stage or impounding level. This applies equally to a weir on a river or the dam of a reservoir, and in each case therefore there is an incentive to build the weir-crest or overflow-cill of uniform level and considerable length. A substantial discharge of water can then pass with little depth over the crest or cill; and it is upon the measurements of this depth—which may be easily affected by such factors as wind, waves, weed-growth or the roughness of the masonry—that the estimates of discharge primarily depend. Equally, any small error in the adjustment of the recording-instrument will have a great effect upon the calculations of discharges. There is naturally often a wish to make use of existing arrangements as far as possible to secure the extra advantage of water-measurement but we feel bound in most cases to regard with suspicion measurements effected entirely by a single structure of uniform level and great length.

60. Where opportunity permits such a structure should, we suggest, be compounded, i.e., converted into a series of weirs or cills symmetrically arranged at different levels. Even if each difference of level were as little as three inches it would in some cases increase appreciably the accuracy of the measurements. Obvious alternatives are a series of V-notches or a single but very wide and very shallow V-notch, such as one in Lancashire which is 40 feet wide and 4 feet deep. The suggestion of a compounded weir may be thought inapplicable where a reservoir overflow-cill or a river-weir is concerned, but we have nevertheless encountered cases of river-weirs in which it appeared possible to make the desired change, by either a downward excision in the weir, or the construction of rising shoulders on it at either side. The compounded weir, however, with its sudden expansions of widths and carrying capacity usually needs an instrument with a record-scale that changes as the water draws level with each successive weir-crest, but this is by its nature not only more complicated and costly to produce but also, even if only slightly out of adjustment, liable to err seriously in its results. It is hoped that research in this matter may eventually enable engineers or instrument-makers to produce a design of weir that will avoid some of these difficulties for their instruments.

61. The estimates of discharge depend in the second place upon mechanical instruments—recorders and integrators—whose results must in many cases lose accuracy as the ratio of maximum to minimum discharge grows. If then the total range of variation has to be dealt with by a single measuring-

structure, this loss of accuracy in the mechanical instruments may be great. We have encountered cases where for this reason the integrator has deliberately been designed not to deal with the smaller discharges, which then need to be measured in some other manner and as a result may be ignored. If however the range of measurement can be divided into two parts and the gauging for each part conducted at a point independent of that used for the other the range of discharge in either case will be much less than it would be with a single measuring point, so that the accuracy will be improved and the measurements will be more comprehensive.

62. Dual arrangements could moreover probably be arranged to solve another trouble of which we have become aware, viz., the tendency of weirs, when the stream-stage is high, to become drowned or to cease to have an aerated nappe. We are of opinion that these things happen much more frequently than many weir-owners realise and that, whatever the state of affairs, each weir-owner should be more precisely informed concerning it than is at present usual.

63. A first step to be taken is the one advocated in paragraph 19 of the "Memorandum on the Water Survey of a River System"*, namely, the simultaneous observation from time to time of upstream and downstream water-levels at the weir. From these the relationship between the two water-levels can be determined and the discharge or the upstream stage at which drowning begins can be deduced. The records of the weir will show how frequently such a discharge or stage is reached, and it can then be decided whether or to what extent allowance should be made for the alteration of conditions that then arises in any computations based on the records.

64. In tendering this advice we have not forgotten that in certain conditions, e.g., if the weir be broad-crested and a standing wave be formed by the water, a high degree of submergence may occur without affecting the validity of the initial discharge formula used for the weir. We understand however that the majority of clients who approach makers for discharge-measuring instruments are unable to state the stage-discharge conditions of the points selected for gauging, so that the instruments have to be designed for clear overfall conditions, regardless of what actually occurs. If as the result of investigations it proves desirable to decide afresh what discharges the river carries at higher stages, the steps to be taken must naturally depend upon local conditions. In some cases a second weir that is unsuitable for measuring small discharges but which is found to be undrownable may be available. In others it may be necessary to use a current-meter or float to measure velocities.

* His Majesty's Stationery Office, 1936. Price 6d. net.

65. The principle of dualism in arrangements may well be applied also to some of the stations in which measurements of discharge are made partly or entirely by current-meter. High-stage and low-stage discharges can sometimes best be measured by meter at different stations; in other cases the small discharges can be suitably measured by a weir or sluices and the large discharges by a current-meter.

66. The several measures which we have recommended above, as well as in the Memorandum already quoted, will naturally fail to secure their aim unless the condition of the arrangements installed is continually watched. Such matters as the removal of deposits from weir-pools and of fouling from venturi-meters, or the testing of the adjustment of recording-instruments, are of vital importance if errors are to be minimised. Nevertheless we find that they are at times forgotten. We understand that it is possible to arrange with firms supplying meters and instruments for periodical inspections and tests of the installations to be made.

67. An additional field-test is to pit one measuring-instrument against another. The rating of most instruments installed at gauging stations is based upon theoretical considerations or observations of their behaviour, or that of models, in ideal or laboratory conditions. Tests of weirs and throated flumes in the field are often admittedly difficult to arrange but might be made more frequently than they are.

68. There is an additional test of any station that need not be made at site and that is, as mentioned in paragraph 53, to compile the results obtained and render them into some simple form, e.g., monthly and annual run-off, in which they can be compared with the rainfall of the same area for the same period, and with the run-offs and the rainfalls for other years or of neighbouring areas. We know of cases where such a comparison has revealed discrepancies that were inexplicable, until they led to the examination of an instrument and the discovery that it was out of adjustment.

69. The recommendations made above are naturally couched in general terms. As evidence that they are nevertheless of practicable character, we would mention the following as examples, amongst others, in which the engineers concerned have already acted on the lines mentioned, in some cases independently of any suggestions from us:—

Dual gauging-points (a weir below the reservoir for small flows and the reservoir overflow-cill for large ones): River Taff at Llwyn-on Reservoir (Cardiff Corporation) and River

Caerfanell, a tributary of the River Usk, at Talybont Reservoir (Newport Corporation).

Dual measuring-arrangements (a notched fall for small flows to supply and a venturimeter for large ones, also a drownable notched fall and short weir for small flows to the river and an undrownable long weir for the large ones); River South Teign at the Fernworthy gathering ground (Torquay Corporation).

Study of relationship of upstream and downstream water-levels: River Dee at Erbistock (River Dee Catchment Board): River Ouse (Yorks) at five weirs (West Riding of Yorkshire Rivers Board).

Checking of calibration of gauging-devices by other instruments: a throated flume on the River Chew, checked by the use of a current-meter (Bristol Waterworks Company).

70. We have been much impressed with the necessity that those who are sharing in the Survey shall be able to keep within reasonable limits the volume of office-work involved. We have noticed that daily quantities of surface water containing as many as nine significant figures are sometimes recorded as having been observed, possibly because either the integrating machine of the recorder contains that number of dials (or more), or a quantity expressed in fewer numbers, perhaps only three or four, has been observed and then multiplied by a constant that is numerically as lengthy, the result being quoted exactly, regardless of the degree of accuracy possible in the measurement.

71. In the Surface Water Year-Book of Great Britain, 1935-36, all individual discharge measurements are quoted to three significant figures only and usually not to a finer degree than 0·1 cusecs. The quantities have been calculated to a fourth figure and then rounded off as already stated. We think that these practices are appropriate to the accuracy obtainable in the measurements and statistically sound as well as labour-saving and that engineers may find it advantageous to adopt some such procedure. We have been interested to find that at least one water undertaking has of its own volition adopted the rule of three significant figures for surface-water quantities and considers it to yield satisfactory results. It may with unskilled staff in the field be prudent to make them continue to record readings or calculate quantities at length; what is suggested however is that numerical simplification should occur when possible in the office-records and computations.

72. We should like to take this opportunity of recording our appreciation of the assistance which we have always received

from the staffs of the various Government Departments connected with the Survey.

We have the honour to be, Gentlemen,

Your obedient Servants,

(Signed) H. G. Lyons (*Chairman*).

Chas. H. Bird.

W. S. Boulton.

Geo. Dallas.

G. J. Griffiths.

S. Hibbert.

Clement D. M. Hindley.

S. R. Hobday.

W. A. Millar.

David Paul.

B. Verity.

R. F. Tyas.

(*Secretary*.)

1st December, 1938.

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